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**CATALOG OF EXPERIMENTAL PROJECTS FOR
A FISSIONING PLASMA REACTOR**

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CATALOG OF EXPERIMENTAL PROJECTS FOR A FISSIONING PLASMA REACTOR

by Chester D. Lanzo
Lewis Research Center

SUMMARY

This report documents work done to date at the NASA Lewis Research Center on small scale fissioning uranium plasma experiment proposals. Eight experiments are described which were evaluated for a 4-megawatt driver reactor. The driver reactor described in the report is light water-cooled and moderated of the MTR-type. The cavity of the driver reactor has a flux capability of 10^{15} neutrons/cm²-sec, cavity pressure of 2000 psia with the possibility of uprating to 3000 psia, and a cavity diameter of 2 ft.

INTRODUCTION

Experimental and theoretical investigations have been conducted to determine the feasibility of a full scale gas core nuclear rocket engine. These investigations took place at the NASA Lewis Research Center in Cleveland, Ohio from 1957 through 1972. The work was terminated in January 1973.

During 1972 the research effort was directed towards systems other than the nuclear rocket. These small scale tests would have utilized a fissioning uranium plasma produced in a driver reactor. This reactor would have produced an intense, high temperature, highly radiant heat source with heat fluxes approximating those of the full scale concepts. A feasible configuration for the desired driver reactor was obtained but the final design was not optimized. Experiments were evaluated for this reactor. Eight of them are described herein.

The principal theoretical advantage of a fissioning uranium plasma thruster system is the extremely high propellant temperature which could help produce high specific impulse and thrust (ref. 1). This capability would be a major breakthrough in rocket propulsion technology if sufficiently low engine weights and fuel loss rates could be achieved.

The original purpose of this compilation was to determine what parts of each experiment could be common to each other. The common parts would be a major factor in the design of the driver reactor.

The present purpose of this report is to document the work done thus far on the project as a base for any further work later on.

DESCRIPTION OF DRIVER REACTOR FACILITY

The Fissioning Plasma Reactor Test Facility was to be located in reactor test cell "A" which is located at the Nuclear Rocket Development Station in Nevada. The facility would consist of a special purpose driver reactor containing a two foot diameter cavity in the center of the reactor pressure vessel. The driver reactor was to be built using low temperature existing technology fuel elements and other state of the art reactor components. The driver reactor would supply to the center cavity sufficient neutrons to produce a fissioning plasma at a 4-megawatt power level. All necessary instrumentation, controls and mechanical equipment are included with the outer containment vessel and effluent handling system needed to make the facility safe. The Fissioning Plasma Reactor Facility would enable research to be conducted on many different concepts for generating and utilizing fissioning uranium plasmas, including propulsion reactors, nuclear lasers, and MHD power. These concepts are included in this report and will be described later.

Laboratory research has been conducted at the Lewis Research Center for the past 15 years and the excellent progress to date defines the need for a facility to conduct research using a uranium plasma self-heated by the fission process.

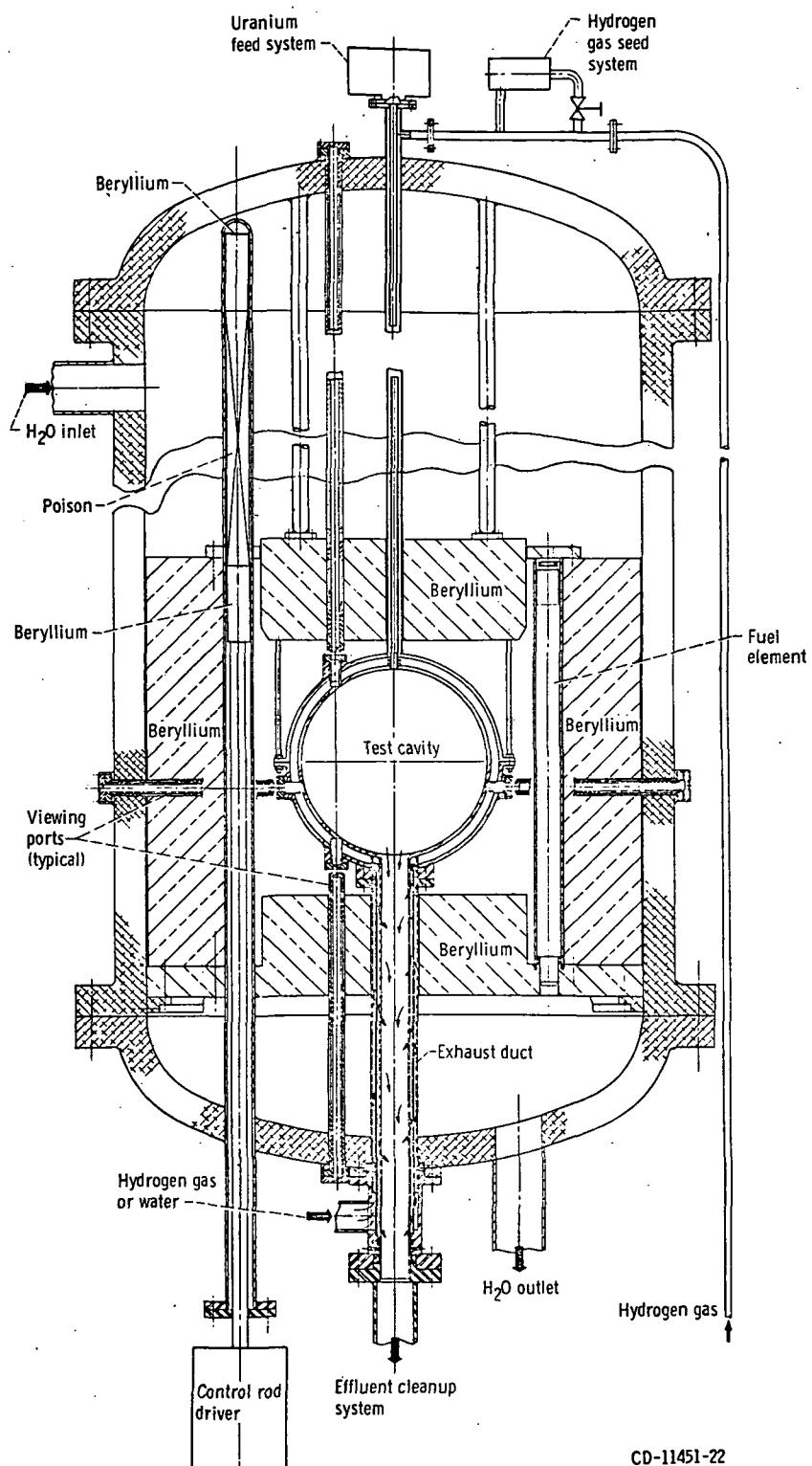
The driver reactor requirements were determined by a cursory study of the 8 test articles submitted for consideration for nuclear testing.

Figure 1 is a preliminary design concept of the driver reactor and shows some of the planned physical requirements thought necessary to carry out most of the experiments.

DRIVER REACTOR SPECIFICATIONS

The pertinent data gathered for the Fissioning Plasma Reactor Facility Driver are listed as follows:

1. Cavity pressure, 2000 psia with possibility of uprating to 3000 psi
2. Cavity flux, unperturbed, 10^{15} neutrons/cm²-sec
3. Coolant gas, argon with capability of future tests with H₂
4. Cavity diameter, 2 ft
5. Test time, 5 min average with a range of 2 to 10 min
6. Upflow test loop
7. Triga-type fuel elements considered with capability of pulsing from 10^{15} to 10^{17} neutrons/cm²-sec



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Figure 1. - Driver reactor. Test cavity pressure, 2000 psi; test cavity diameter, 2 feet; test cavity neutron flux, 10^{15} neutrons/cm 2 -sec.

The common items of concern from a design standpoint for all test articles were determined to be the following:

- (1) Heat and energy generated by the Test Article Heat Disposal Loop
- (2) Effluent clean up system
 - (a) Power level
 - (b) Pressure
 - (c) Test train effluent
 - (d) Primary coolant effluent and H₂ supply system
 - (e) Upflow against downflow requirement
 - (f) Fissionable test material storage and handling
- (3) Test operations

After all of the data were reviewed the test article experiments were placed in the tentative order that each would be pursued for testing in the driver reactor with the greatest possibility of successful operation.

The list, description, and source of each of the experiments in order of future testing is shown in table I.

A table was then made up of all the pertinent data that applied to the individual test articles to determine if all of the experiments could be contained in the driver reactor as it is presently designed.

Table II shows the experiments listed in the probable order of testing in the driver reactor. Also shown are the typical experimental requirements that could be common to all of test articles.

REQUIREMENTS RECEIVED FROM EXPERIMENTS FOR EACH INSTALLATION IN FISSIONING PLASMA RESEARCH FACILITY

The material described in the appendix was received from each of the proposed sponsors in response to a form questionnaire on the uranium plasma experiment requirements for each of the eight anticipated experiments.

A brief introductory description of the anticipated tests is included for the MHD and rotating fluidized bed reactor along with the experimental requirements for the other experiments.

TABLE I. - CATALOG OF EXPERIMENTAL PROJECTS FOR FISSIONING PLASMA REACTOR FACILITY

Experiment	Information source	Description
1. Basic Studies	Gas Core Section, Lewis Research Center, Cleveland, Ohio and Dr. K. Thom, NASA Headquarters	Basic studies and experiments on fissioning plasmas
2. Open Cycle Gas Core (OCGC)	Lewis Research Center, Cleveland, Ohio	Nuclear powered rocket propulsion system
3. Nuclear Light Bulb (NLB)	United Aircraft Research Laboratory, East Hartford, Ct.	Nuclear powered closed-cycle rocket propulsion system
4. Rotating Fluidized Bed (RFB)	Engineering Division, Brookhaven National Laboratory, Upton, N.Y.	Nuclear power and propulsion system
5. H ₂ /H ₂ O	Lewis Research Center, Cleveland, Ohio	Hydrogen fuel gas separated from water using a fissioning plasma
6 (A). Gas Core MHD Power	Richard Williams, Georgia Institute of Technology, Atlanta, Ga.	Electrical power generation from a fissioning plasma
6 (B) Gas Dynamic Laser		Laser energy generation from a fis- sioning plasma
7. Fission Laser	Lewis Research Center, Cleveland, Ohio	Laser energy source using fissioning plasma particles
8. Nuclear Pumped Laser	University of Florida, Gainesville, Fla.	Fission fragment induced luminescence

TABLE II. - EXPERIMENTAL REQUIREMENTS FOR FISSIONING PLASMA REACTOR FACILITY CAVITY

Experiment	Cavity geometry	Cavity pressure, atm	Cavity power, MW	Amount of fissionable material inserted into cavity, g	Thermal neutron flux (<0.12 eV)	Minimum experimental run time at cavity power	Comments
1. Basic Studies	Sphere; 2-ft diam.	200	3	-----	1x10 ¹⁴	-----	Any of the experimental configurations might be used.
2. Open Cycle Gas Core	Sphere, 2-ft diam. Al or C desirable from neutronics standpoint	200	3-5	572 total uranium 93% enriched	$a3 \times 10^{14}$ to 5×10^{14} $b1 \times 10^{14}$ to 1.61×10^{14} Minimum values for reactor	30 to 60 min to establish flow, 15 min full power; 5 min hot run full power	Sonic nozzle desirable; upflow probably necessary.
3. Nuclear Light Bulb	Cylinder; $5\frac{1}{2}$ -in. radius by 30 in. long	500-700	3-5	-----	30 kW/g $\dot{V}235$	30 min	NLB could be contained in own pressure chamber.
4. Rotating Fluidized Bed	Cylinder; 18-in. diam. by $22\frac{1}{2}$ in. long	16-67	3-5	-----	1x10 ¹⁴	3-4 days	12-in. diam. exhaust tube desired. Motor and LH_2 feed system in pressure vessel; reactor is self-cooling
5. $\text{H}_2/\text{H}_2\text{O}$	Sphere; 2-ft diam.	200	3-5	-----	1x10 ¹⁴	30 min	-----
6. Gas Core MHD Power and Gas Dynamic Laser	Cylinder; 4-ft diam. by 4 ft long inside pressure vessel	200	3-5	572 $\dot{V}235$	1x10 ¹⁴	30 min	Sonic flow nozzle needed at exit of core.
7. Fission	Cylinder; 6- to 24-in. diam. by 2 to 6 ft long	1-20	0.01-1	-----	1x10 ¹⁵ to 10 ¹⁸	30 min	Four windows and two mirrors required; laser test cavity
8. Nuclear Pumped Laser	Aluminum sphere coated with U_{308}	0-200	3	572 $\dot{V}235$	1x10 ¹⁵	2 hr	Optical port through reactor cavity and vessel.

^aPerturbed.^bUnperturbed.

APPENDIX - POSSIBLE EXPERIMENTS FOR THE FISSIONING PLASMA FACILITYOPEN CYCLE GAS CORE AND BASIC STUDIES EXPERIMENTS***I. Facility**

Data equipment - Do not know. Measurements required are temperature, pressure, and flow rates of all storage facilities. Also, chemical sampling and analysis and/or spectrographic analysis of process materials (H_2 , N_2 , or He , U^{235} , U^{238}) will be needed. About 200 information channels needed.

Display equipment - Do not know. Would like to observe cavity conditions, such as fuel position, H_2 temperature, pressure, flow rate, and composition if possible.

Flow systems

H_2 propellant, 34-340 g/sec, 200 atm, ≤ 300 K, 250-2500 kg

N_2 or He purge, ?

U^{238} seed, 11-110 g/sec, 200 atm, ~ 300 K, 90-900 kg

U^{235} fuel (fully enriched uranium), 1.1 g/sec, 200 atm, ~ 300 K, 10 kg

H_2 coolant (Nerva model), 3×10^4 kg/hr, 200 atm, ~ 300 K, 5×10^4 kg

Effluent handling

Power, 60-90 Mw (40-60 Nerva)

Effluent, 99.96% H , 0.037% U^{238} , 0.0037% U^{235} (based on 5 to 1 H_2 dilution for cooling). 300 K, 200 atm, 12.6 - 126 l/sec will contain ~1 g of fission products.

(Nerva model) composition same as above with the addition of H_2 coolant, 300 K, 200 atm, 8600 l/sec

Hot lab equipment - Need crane to remotely disconnect and remove cavity and transport to hot cell; hot cell with disassembly capability; chemical and physical analysis

II. Test Reactor

Startup - U feed system. Pressure balancing of cavity and reactor pressure level. Scram system must account for rapid reactivity in-

* C. Whitmarsh, Lewis Research Center.

crease in cavity. Cavity effluent at ~3900 K must be cooled to ~300 K by addition of H₂ (~5/1) at cavity exit. Provision must be made to account for the pressure created by coolant addition. Need 30 min to 1 hr to establish flow and fuel loading.

Inlet lines - Flow passage needed for H₂ propellant (seeded) and one for uranium fuel. Coaxial passages with outer diameter of ~3" must be shielded from neutrons.

Test cavity - Sphere with a 2 foot inside diameter can be made of Al, C, or other material, preferably with low neutron cross section and high melting point.

Neutron flux	Fueled	Unfueled
H ₂ O cooled		
ϕ_{Th} (E < 0.12 ev) ^a	1×10^{14}	Unperturbed
ϕ_{epi} (0.12 ev-0.07 Mev)	3.1	
ϕ_f (E > 0.07 Mev)	2.2	
Nerva		
ϕ_{Th}	0.9×10^{14}	2.8×10^{14}
ϕ_{epi}	4.1	3.0
ϕ_f	1.6	1.0

^aLess than 0.12 ev is thermal flux.

Shutdown - Disconnect system for cavity removal. Pressure balancing.

Test time - 30 min to 1 hr to establish flow and fuel loading, run for 5 min and purge cavity

Turnaround - 1 to 2 months if cavity has to be replaced

Frequency - 10 to 15 runs per year

III. Test Train

General - Need to measure cavity conditions of temperature, flow distribution, pressure, composition, flux level and rate of change. Also cavity liner temperature at many points (~100).

For safety need a feed propellant flow control based on cavity temperature and pressure, liner temperature, and flux level. Also reactor scram due to liner temperature or cavity power.

Steady state cavity pressure of 200 atm must be balanced within ~5% of reactor pressure.

Outlet line - One passage for effluent, possibly jacketed for cooling; ~3" i.d. Effluent must be mixed with H₂ (or H₂O) to cool to ~300 K. Also walls should be film cooled to prevent uranium and fission product deposition.

Other - Cavity liner must be isolated such that wall burnout will not affect the integrity of the reactor.

NUCLEAR LIGHT BULB TEST CELL EXPERIMENT

I. Facility

A. Data recording, storage, and retrieval equipment

1. Pressure transducer and thermocouple channels (~50)
2. Flowmeters (~10)
3. Spectral emission measurement system
4. Strain gages (3-5)

B. Real-time display equipment

1. Flowmeters (~6-10)
2. Thermocouples (~6-10)
3. Plasma viewing system
4. Pressure transducers (2-5)

C. Flow systems

1. Operating pressures, 300-500 atm
2. Material inlet temperatures ~300 K
3. Flow control by orifices primarily
4. Table of flow requirements:

Material	Flow rate, g/sec	Storage capacity, kg
Argon gas	40-200	120
Hydrogen gas (Coolant for fuel region tests)	1000-3000	1800
Hydrogen gas (propel- lant heating tests)	5-30	18
UF ₆ (liquid or gas)	5-50	30
Tungsten particles	5-30	18
Uranium particles	3-30	18

D. Effluent handling

1. Test power level 600 to 1500 kW

2. Test effluent will be mixture of U, UF₆, A, H₂, fission fragments with flow rates equal to those given in paragraph I.C.4. Effluent will discharge into ambient reactor operating pressure with mixed-mean temperature of ~500 K.

E. Hot Lab Equipment

1. Remote disassembly and inspection facility required for post-test examination of test assembly components.

II. Test Reactor

A. Operating times

1. Start-up, 3-5 min
2. Shutdown, 3-5 min
3. Test time, 3-10 min
4. Experiment turn-around time, 10-30 days
5. Experiment frequency, 15-45 days

III. Test Train

A. General Requirements

1. Data instrumentation:
Pressure transducers (10-20)
Thermocouples (30-50)
Strain gages (3-5)
2. Experiment safety instrumentation:
Pressure transducers
Thermocouples
Strain gages
3. Pressure level, 300 to 500 atm
4. Electrical requirements, 110 V a.c. and 24 V d.c.
5. Cooling not required unless driver reactor causes heating of components or detection devices and instrument shield need cooling.

B. Inlet Lines

1. Flow passages:
Number of passages, 5-7
Argon buffer gas, 1.27 cm i.d.
Hydrogen coolant, 1.90 cm i.d.
Fuel injection, 0.2 cm i.d.
Hydrogen propellant, 0.6 cm i.d.
Spectral emission viewing tubes (1-3):
0.1 cm i.d.

C. Test Cavity

1. Cylindrical shape, 20 cm i.d., 53 cm length
2. Materials, aluminum and fiber glass
3. Pressure, 300 to 500 atm (We will provide our own pressure vessel.)
4. Neutron flux should provide as high a value of kW/gm of U²³⁵ as possible. Neutron spectrum is not a critical parameter for these tests.

D. Outlet Lines

1. Flow passages:
 - Number of passages, 2-4
 - Hydrogen coolant, 2.54 cm i.d.
 - Effluent mixture, 2.54 cm i.d.
 - Instrumentation coolant (size unknown)

IV. Other Requirements

- A. We may need an instrument package near experiment to detect and process spectral emission from plasma. This package may need shielding and cooling.

ROTATING FLUIDIZED BED EXPERIMENT

Introduction

The rotating fluidized bed reactor was initially proposed for rocket propulsion by L. P. Hatch, W. H. Regan, and J. R. Powell at Brookhaven National Laboratory in 1960 (refs. 2 and 3). The fuel in this system is in the form of small diameter particles that are retained by centrifugal force in a rotating cylindrical structure to form an annular core. The use of small fluidized particles for the reactor fuel offers the following specific advantages:

1. The large surface-to-volume ratio of the fuel and the high fuel-to-coolant heat transfer coefficient permits very high rates of heat transfer with a minimum temperature difference between the fuel and gas stream.
2. Since the primary structure remains cool, design requirements are dictated by high temperature stability of the fuel rather than structural factors which are limiting in conventional solid fuel element nuclear propulsion systems.
3. The volume and mass of material that must be handled in loading and unloading fuel is less than that handled in comparable solid fuel element systems and refueling of the core is simplified.

4. The fuel particles are retained in the core by centrifugal force and the fuel loss problems that are characteristic of gas core concepts are minimized.

Thus, the rotating fluidized bed reactor promises to avoid many of the problems that limit the performance and suitability of solid fuel elements and gas core systems. High gas temperatures and a high specific impulse can be achieved, with the limit dependent on fuel particle melting and sintering properties.

I. Facility

Data recording, storage, and retrieval equipment

Real time display equipment

Flow systems

Gases hydrogen, 0.1 to 2.0 lb/sec, 250 to 1000 lb/sq in., run 2 to 10 min, 240 to 1200 lb H₂

Liquids

Solids (nonfissionable), Zircalloy and Inconel

Solids (fissionable), UCZr

Effluent handling

Test power level, 5 to 50 MW

Test effluent - Similar in quantity to plasma rocket but in lesser concentrations with particulates containing U and fission products for examination of fuel and components

Hot Lab equipment

II. Test Reactor

Set-up, 3 to 4 days

Shut-down

Test time, 3 to 4 days

Experiment turn-around time, 1 to 2 weeks

Experiment frequency, 10 to 20 test/yr

III. Test Train

General - 200 thermocouples, 25 pressure transducers, reactor noise measurements, flux measurements, light pipes, monitor motor characteristics

Inlet line (s):

No. of flow passages, one

Size(s), 6 in.

Cooling

Test Cavity:

Shape and size, 18 in. right circular cylinder
 Materials, Zircalloy and Inconel
 Pressure
 Neutron flux
 Thermal $\sim 10^{14}$
 Epi-thermal
 Fast
 Thermal flux spectrum

Outlet Line(s):

Number of flow passages, One
 Size(s), 1 to 6 in.
 Cooling, Regenerative cooling

H₂ FROM H₂O EXPERIMENT*

I. Facility

Data recording, storage, and retrieval equipment - Same ± 10 to 20 channels

Real time display equipment - Same ± 10 to 20 channels

Flow systems

Gases, Steam (200 atm, 2-10 lb/s)
 Liquids, Water (200 atm, 100° F, 10 to 50 lb/s)
 Solids (nonfissionable), 0.5 to 2 lb/s
 Solids (fissionable), 0.1 to 0.5 lb/s

Effluent handling

Test power level, 60 to 90 MW
 Test effluent, 1000° to 2000° F, 10 to 50 atm, 0.5 lb/s H₂,
 5 lb/s O₂, 5 lb/s H₂O (composition, flow rate, temperature,
 pressure, activity, other)

Hot Lab equipment - Need crane to remotely disconnect and remote cavity and transport to hot cell; hot cell with disassembly capability; chemical and physical analysis.

II. Test Reactor

Startup - U feed system. Pressure balancing of cavity and reactor pressure level. Scram system must account for rapid reactivity in-

* A. Kascak, Lewis Research Center.

crease in cavity. Cavity effluent at ~3900 K must be cooled to ~300 K by addition of H_2 (~5/1) at cavity exit. Provision must be made to account for the pressure created by coolant addition. Need 30 min to 1 hr to establish flow and fuel loading.

Shutdown - Disconnect system for cavity removal. Pressure balancing.

Test time - 30 min to 1 hr to establish flow and fuel loading, run for 5 min and purge cavity

Experiment turnaround time - 1 to 2 months if cavity has to be replaced

Experiment frequency - ?

III. Test Train

General - Need to measure cavity conditions of temperature, flow distribution, pressure, composition, flux level, and rate of change. Also cavity liner temperature at many points (~100).

For safety need a feed propellant flow control based on cavity temperature and pressure, liner temperature, and flux level. Also reactor scram due to liner temperature or cavity power.

Steady state cavity pressure of 200 atm must be balanced within ~5% of reactor pressure.

Inlet line(s):

Numbers of flow passages, 2 (water and steam)

Size(s), 10 lb/s steam, 50 lb/s water

Cooling

Test cavity - Sphere with a 2 foot inside diameter can be made of Al, C, or other material, preferably with low neutron cross section and high melting point.

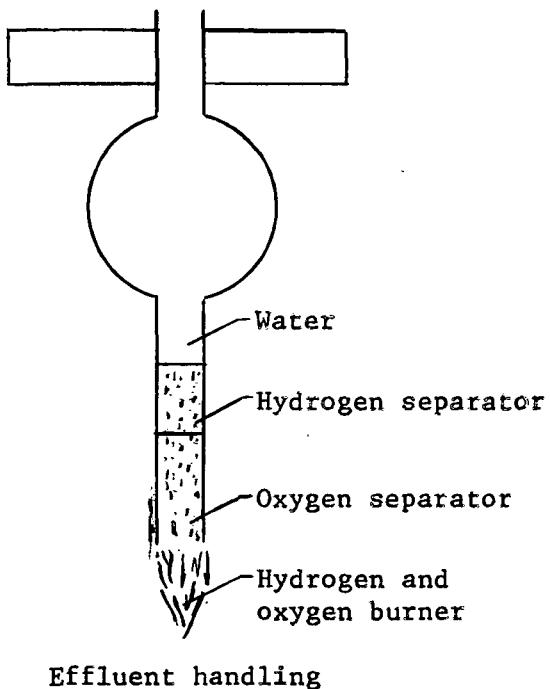
Neutron flux	Fueled	Unfueled
H_2O cooled		
ϕ_{Th} ($E < 0.12$ ev) ^a	1×10^{14}	Unperturbed
ϕ_{epi} (0.12 ev-0.07 Mev)	3.1	
ϕ_f ($E > 0.07$ Mev)	2.2	
Nerva		
ϕ_{Th}	0.9×10^{14}	2.8×10^{14}
ϕ_{epi}	4.1	3.0
ϕ_f	1.6	1.0

^aLess than 0.12 ev is thermal flux.

Outlet line - One passage for effluent, possibly jacketed for cooling; ~3" i.d. Effluent must be mixed with H₂ (or H₂O) to cool to ~300 K. Also walls should be film cooled to prevent uranium and fission product deposition.

IV. Other Requirements

Cavity liner must be isolated such that wall burnout will not affect the integrity of the reactor. The exhaust nozzle must have enough room so that a frozen condition can be created downstream of the nozzle and the H₂ and O₂ can be separated.



GAS CORE REACTOR MHD EXPERIMENT

Introduction

The proposed uranium plasma reactor experiment would provide an ideal test facility for a demonstration of gas core reactor MHD power generation. The range of the minicore reactor exit temperature, 3500 to 4000 K, is the primary temperature range of interest for MHD power generation with gas core reactors. Likewise, the 200 atmosphere reactor pressure is a realistic pressure for a full scale power reactor. The test reactor facility will therefore permit testing of MHD generators, uranium separators, and other associated equipment under realistic conditions of interest with respect to temperature, pressure, working fluid composition (including uranium and fission products), and the presence of nuclear radiation fields.

An important MHD generator parameter that cannot be determined directly from this experiment is the generator efficiency, because the generators tested would be much smaller than actual generators used in full-scale powerplants. MHD generators benefit greatly from an economy of scale - as the size and power input is increased, the capital cost per MWe decreases and the generator efficiency tends to increase. The power output is proportional to the volume of the duct whereas most loss mechanisms depend on the inside surface area, so as the size and power of generators increase they tend to become more efficient. The small generators to be tested with the mini-core will, however, provide valuable information on electrode survival, and the electrical characteristics of the generators which can be scaled up to full-sized systems. Also, important questions, such as the effect of uranium droplet migration to the electrodes and generator walls can be answered, and various duct configurations can be tested to minimize or eliminate these problems.

At a later stage in the test program, uranium separators, of the type proposed for the gas core MHD powerplant, can be tested at the pressure vessel effluent exit.

These tests can be conducted independently of the MHD generator test.

The MHD test could be made essentially independent of the reactor test since it is located in the reactor exit duct and has no effect on the reactor itself. The reactor and MHD systems would probably be tested simultaneously.

I. Facility

A. Data Recording, Storage, and Retrieval

400 channels of digital or analog data recording and storage on IBM compatible magnetic tape or equivalent. This would be sufficient for the MHD test. Data to be recorded include currents and voltages of each MHD electrode, coolant temperatures and flow rates, temperatures at as many as 50 points in the duct, magnet current, heat fluxes, and magnetic field strengths. Possibly also a videotape recorder.

B. Real Time Display Equipment

Digital or analog display of voltages, currents, temperatures, and other parameters of interest, possibly coupled with a panel of lights to indicate if preset maximum permissible temperatures are exceeded. If a fiber optic guide can be located through a side wall of the duct, television monitoring and display of the duct interior may be possible.

C. Flow Systems

1. Pure hydrogen or helium at a flow rate of 0.1 lb/sec or higher for the reactor and for film cooling the MHD generator and nozzle.
2. Uranium as a wire (coaxial-flow-reactor) or as an aerosol of particles in hydrogen or helium carrier gas. A separate inlet line for the aerosol should be provided so reactors can be tested with simultaneous flows of aerosol into the center, and pure gas or a more dilute aerosol around the outside of the fuel region.
3. Cesium vapor injection into nozzle with a maximum flow of 0.02 lb/sec.
4. Liquid nitrogen flow through magnets.
5. H_2O coolant must be provided for the electrodes.

D. Effluent Handling

Same as for cavity test. If helium is used in the reactor, problems may be reduced.

E. Hot Lab Equipment

Manipulators with microzoom TV monitoring for remote disassembly and closeup examination of the MHD generator after test.

II. Test Reactor and MHD Generator

A. Startup

MHD generator started by starting coolant flow to the MHD electrodes and liquid nitrogen to the magnets, then turning on the magnet current. Electrode water coolant flow and wall film cooling must continue whenever reactor is operating. Reactor is started up by flowing a uranium aerosol into the cavity. Some reactor tests may require a continuing aerosol flow of a mass fraction of uranium of about 2 into the central region of the reactor, and pure gas or a more dilute aerosol injected tangentially along the cavity liner.

B. Shutdown

The generator may be made inactive by turning off the magnet current, or shutdown completely by also stopping the coolant flows. In the inactive mode, the generator is simply part of the exhaust duct, and acts as a throttling valve due to the

pressure drop across the nozzle. The water coolant to the MHD duct walls and electrodes and the gas film-cooling the walls and nozzle must remain on whenever the reactor is operating.

C. Test Time

The generator test time would be less than or equal to the reactor test time. Generator tests could be conducted simultaneously with but almost independent of the reactor tests. After removal to the hot labs, disassembly and inspection would require at least as much time as that for the reactor test vessel.

D. Experiment Turnaround Time

The MHD duct would probably be attached to the exhaust duct below the reactor, and would be pulled out of the pressure vessels with the reactor. Reactor tests could be conducted with or without an MHD generator attached. The time from test to inspection to redesign to construction of a new duct and testing the new duct could take six months to a year, but if several duct designs are to be tested, the time between tests should be about the same as in the reactor alone.

E. Experiment Frequency

Probably a minor fraction (say 20%) of the reactor tests would include MHD generator tests. Frequency could vary from one per month to as low as two per year, depending on the level of effort involved.

III. Test Train

A. General

Data instrumentation - Required for measuring and recording voltages in the KV range, electrode currents up to perhaps 100 A, temperatures at different locations in the coolant lines, and on the inside surfaces of the duct, a moisture alarm in the MHD exhaust, pressure sensors (static and stagnation) in the duct, and other parameters. Estimated number of channels:

Voltages in the KV range	40
Currents to 100 A	40
Thermocouple outputs	150
Low voltages from sensors	70
Other channels	100

Experiment safety instrumentation - Would include a moisture alarm to indicate MHD side wall or electrode burnout with subsequent moisture (cooling water) leakage into the MHD exhaust. Alarms or other suitable indicators must be provided to indicate excessive temperatures at critical points or a coolant interruption. Stoppage of any coolant flow should automatically scram the entire experiment, including the reactor.

Pressure level - Sensors will measure static and stagnation pressures in the reactor, nozzle (if possible), feed and exit lines, and at critical points in the MHD duct. Coolant pressures will also be monitored.

Electrical instrumentation - Will record thermocouple voltages and the output of other sensors previously discussed.

Cooling requirements include (1) two pure or seeded hydrogen (helium) flows to film cool the MHD duct walls and to film cool the nozzle, (2) three distilled water loops to cool the MHD electrodes, the MHD side walls, and other parts of the experiment subject to excessive gamma heating, and (3) a liquid nitrogen flow to the magnets.

B. Inlet Lines

Type	Number	Sizes	Cooling
Liquid N ₂	1	1 in. insulated	None
H ₂ O	3	2 in. or less	None
H ₂ (or He)	4	2 in. or less	None

The four H₂ lines include two for the reactor, one for the nozzle, and one for the MHD duct. Any or all of these flows may be seeded.

C. Test Cavity and MHD Generator

A space at least 4 feet in diameter (preferably 6) and at least 4 feet long (preferably longer) will be required inside the pressure vessel, below the lower Be reflector, for the MHD experiment package, which will include the magnet. The duct itself will be much smaller than the magnet. It may be desirable to leave the magnet in the reactor on a more-or-less permanent basis and only withdraw the duct between experiments. At present it appears that the facility specifications should provide for removal of the lower reflector along with the upper reflector, cavity reactor and MHD duct at the end of test.

D. Outlet lines

Type	Number	Sizes	Cooling
Liquid N ₂	1	1 in. insulated	None
H ₂ O	3	2 in. or less	None
Exhaust	1	6 in. (?)	Yes, water cooling

IV. Other Requirements

A. Reactor Exit Duct

The exhaust duct from the reactor exit to the nozzle below the reflector should be lined with coated graphite, or other refractory material such as boron nitride, to reduce heat loss from the exit gas in this part of the exhaust duct to an absolute minimum consistent with maintaining the integrity of the exhaust duct. The material may be cooled by a hydrogen flow through the material or, if necessary, by transpiration cooling. A flow velocity as high as 100 meters/sec (about Mach 0.1) may be desirable in this part of the duct to minimize the residence time of gas in the duct and thereby minimize the radiant heat loss from the gas to the exhaust duct walls.

It should be possible to operate the exhaust duct below the MHD exit as close to 1 atmosphere of pressure as possible. In order to test the MHD generator over a range of pressure ratios, it will be necessary to provide means to vary the exhaust pressure here from as low as possible up to, perhaps, 50 atmospheres. In view of this fact, it is recommended that the exhaust line pressure below the MHD duct be variable from 1 atmosphere to the reactor pressure so the reactor can be operated without an MHD duct or nozzle to provide for a pressure drop.

Suitable flanges must be provided on the exhaust duct to remove a section at least 4 feet long and insert the MHD experiment.

B. Resistor Bank

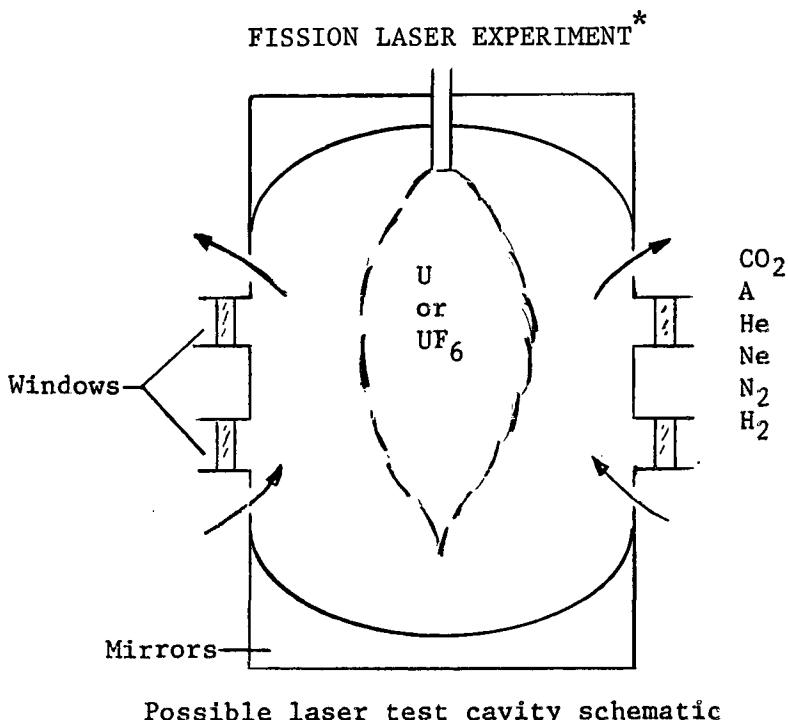
A resistor bank should be provided to dump as much as 100 KW of electricity produced by the MHD generator. This is a minor item.

C. Electrical Connections

Connectors must be provided in the pressure vessel for transmission of as many as 400 low voltage signals and as many as 40 separate 100 A lines will be needed for transmission of the MHD output power and operating pumps. Separate electrical loads will be connected to each electrode pair.

D. Cryogenic Storage

Cryogenic storage should be provided for about 200 liters of liquid nitrogen.



I. Facility

Data equipment - Do not know. Measurements required are temperature, pressure, and flow rates of all storage facilities. Also, chemical sampling and analysis and/or spectrographic analysis of process materials (H_2 , N_2 or He, U235, U238) will be needed. About 200 information channels needed. Also light beam intensity and gain data recorders.

Display equipment - Do not know. Would like to observe cavity conditions, such as fuel position, H_2 temperature, pressure, flow rate, and composition if possible. Need mirror and window temperature and beam intensity readouts.

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Flow systems - On fuel side should be capable of injection UF₆, powdered uranium, or uranium wire. On laser gas side should have separate gas storage systems for CO₂, A, He, Ne, N₂, and H₂ at up to 200 atm storage pressure, capable of 0.01 to 10 lb/sec gas flow rates.

Effluent handling:

Cavity test power up to 5 MW
 Outlet composition, UrUF₆ + fission products and any of the laser gases
 Outlet temperatures of 300 to 3000 K
 Outlet pressure of 1 atm to 200 atm

Hot Lab equipment - Need crane to remotely disconnect and remove cavity and transport to hot cell; hot cell with disassembly capability; chemical and physical analysis. Precision optics assembly and alignment equipment for replacing or repairing mirrors, windows, or optical detectors. Also optical equipment for measuring irradiation damage to mirror coatings and window materials.

II. Test Reactor Operating Time Schedule

Startup - 30 min to 1 hr to establish flow and fuel loading

Shutdown - Slow shutdown rates for reactor preferred, so as not to thermally shock optical components

Test time and frequency - Probably many (5 to 10), short-duration (1 to 10 min) runs per month

Turnaround time - One month

III. Test Train

A. General

Data instrumentation - Need to measure cavity conditions of temperature, flow distribution, pressure, composition, flux level and rate of change. Also cavity liner temperature at many points (~100); 4 or 5 different probing lasers; 10 to 20 optical and infrared detectors.

Experiment safety instrumentation - 10 mirror or window temperature sensors, 10 mirror or window flux sensors

Pressure level - 1 to 200 atm

Reactor fluxes - 10¹⁵ to 10¹⁸ neutrons/cm² sec thermal

Electrical - High voltage - low current power supply for electric discharge pumping

Cooling - Extra gas cooling of windows or mirrors.

Mirror alignment detectors

B. Inlet Lines

Reactor primary coolant

Flow passage needed for H_2 propellant (seeded) and one for uranium fuel. Coaxial passages with outer diameter of ~3" must be shielded from neutrons.

U or UF_6 feed lines

Lasing gas lines - Four or five lines feeding into single 1 in. pressure vessel penetration.

Window and mirror coolant lines - Gas compatible with lasing gas fed through 1 in. line.

C. Test Cavity

Shape and size - Probably cylindrical with 2 to 6 ft long, and 6 to 24 in. diameter

Materials - Aluminum, stainless steel, or graphite walls with gold-coated Pyrex, copper, or germanium mirrors and Pyrex, quartz or $NaCl$ crystal windows

Pressure - 1 to 200 atm

Neutron flux - 10^{15} to 10^{18} neutrons/cm² sec, with mostly thermal neutrons

D. Outlet Lines, Number, Size, Cooling

One passage for effluent, possibly jacketed for cooling; ~3" i.d. Effluent must be mixed with H_2 (or H_2O) to cool to ~300 K. Also walls should be film cooled to prevent uranium and fission product deposition. Extra provisions for drawing off composition samples.

E. Other Requirements

May need extra pressure vessel penetrations for line of sight through cavity and reactor.

For remote mirror alignment will need mechanical and electrical drive devices.

NUCLEAR PUMPED LASER EXPERIMENT

Part 1

Purpose:

1. To measure fission fragment induced luminescence of different gases
2. To make gain measurement on several gases
3. To attempt to operate a laser cavity inside reactor cavity

I. Facility

Data Recording - x-y plotters (2), strip chart recorder (3), signal averagers or direct access to small computer (IBM 1800 or equivalent). Also tunable dye lasers as a light source.

Real Time Display - Three oscilloscopes for gain measurements (Tektronix 555 or equivalent)

Flow Systems -

Gases: flow meters (Ar, He⁴, He³, CO₂, N₂, H₂). Flow range depending on gas: 1 cc/sec - 10 l/sec. Recirculation system mandatory! (Heat exchangers, pump.)

Effluent Handling - Some of the gases can be discharged through stack - others will have to be stored in tanks. Since the list of gases is not complete, a storage facility is definitely required. The decision specifying which gases can be discharged has to be made by the local reactor operation committee in accordance with the local rules and regulations.

Hot Lab equipment - Radio-chemistry labs for the purpose of fabricating the required U₃O₈ coatings. Regular radio-chemistry laboratory equipment will be sufficient.

II. Test Reactors

Test Time - Up to 2 hours. At low and moderate temperatures.

Turnaround time - Time between experiments: as short as 15 min. Time for inserting experiment into reactor: hard to guess, depends on handling facilities, obviously the reactor has to be taken apart.

III. Test Train: Part of it covered in I

Test Cavity - Aluminum sphere coated with U₃O₈, water cooled.

Pressure: from vacuum up to maximum available.

Neutron flux: maximum available.

Part 2

Purpose: To measure optical radiation properties of uranium plasmas under gas core reactor conditions (emission coefficient, optical thickness, electron temperature, gas temperature, ionization stage, deviations from equilibrium for the population densities of atomic and ionic levels)

I. Facility

Data Recording - x-y plotters, strip chart recorders, oscilloscopes, access to small computer. Spectrographs (recommend 3.4 m Ebert from Jarrell-Ash), 2m Vacuum Spectrograph from McPherson; 1 m Czerny Turner grafting spectrograph (McPherson or equivalent). Several small Monochromators (1/4 m or 1/2 m).

II. Test Reactor - See Part 1.

III. Test Train - See Part 1.

IV. Test Cavity - See Part 1.

V. Other Requirements - A consumable wing shaped tungsten tube has to be inserted into the cavity beyond the layer of seeded hydrogen gas to allow optical access to the plasma core. It is expected that the outer tip of this tube will vaporize, therefore, a feed mechanism has to be provided. The tube has to be purged with high pressure unseeded hydrogen or helium in order to blow away any particulate matter in the light path. This is an involved scheme, which requires a separate development effort, before it can be put into the reactor.

General Remarks

A. It is desired to have an optical port going all the way through reactor vessel and cavity. The through-port is mandatory for absorption and gain measurements.

B. It is desired to have a cross installed at the discharge line, having two windows which form a through-port for emission and absorption measurements. This would allow to measure the properties of the discharge (temperature, contamination by uranium, aluminum).

For safety reasons it is advisable to install a small monochromator (Jarrell Ash 1/4 m or McPherson 1/2 m) permanently at this location and monitor a prominent aluminum line at all times. Uranium lines should also be monitored. This diagnostic cross should be located at a point in the discharge line, where the exhaust gas (hydrogen) is still sufficiently hot to excite the impurities. If this is not feasible, a part of the exhaust should be syphoned off and reheated by R. F. heating, in order to make sure all metals are vaporized and

emitting. Detailed calculations can be made using Saha's equation and the equation for line intensities. We have suitable codes available.

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